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1.	Your reference	P/61682
2.	Patent application number *(The Patent Office will fill in this part)*	**9824800.8** 12 NOV 1998
3.	Full name, address and postcode of the or of each applicant *(underline all surnames)*	Marconi Electronic Systems Limited The Grove Warren Lane Stanmore Middlesex HA7 4LY
	Patents ADP number *(if you know it)* If the applicant is a corporate body, give the country/state of its incorporation	UK 7524069001
4.	Title of the invention	Scanning of Electromagnetic Beams
5.	Name of your agent *(if you have one)*	Andrew Walker
	"Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)* Patents ADP number *(if you know it)*	GEC Patent Department Waterhouse Lane Chelmsford Essex CM1 2QX 6528202001
6.	If you are declaring priority from one or more earlier patent applications, give the country and the date of filing of the or of each of these earlier applications and *(if you know it)* the or each application number	Country / Priority application number *(if you know it)* / Date of filing *(day / month / year)*
7.	If this application is divided or otherwise derived from an earlier UK application, give the number and the filing date of the earlier application	Number of earlier application / Date of filing *(day / month / year)*
8.	Is a statement of inventorship and of right to grant of a patent required in support of this request? *(Answer 'Yes' if:* *a) any applicant named in part 3 is not an inventor, or* *b) there is an inventor who is not named as an applicant, or* *c) any named applicant is a corporate body* *See note (d)*	Yes

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Description	13
Claim(s)	0
Abstract	0
Drawing(s)	2

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Priority documents

Translations of priority documents

Statement of inventorship and right to grant of a patent (Patents Form 7/77)

Request for preliminary examination and search (Patents Form 9/77)

Request for substantive examination (Patents Form 10/77)

Any other documents (Please specify)

11. I/We request the grant of a patent on the basis of this application.

Signature Andrew Walker

Date 12.11.98

12. Name and daytime telephone number of person to contact in the United Kingdom

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DUPLICATE

SCANNING OF ELECTROMAGNETIC BEAMS

This invention relates to a device which is adapted to be positioned in the path of a beam of electromagnetic radiation to control its direction. The invention is particularly, but not exclusively, concerned with devices for directing microwave radiation.

The term microwave is generally understood to refer to the part of the electromagnetic spectrum between infra-red radiation and radiowaves. Typically this is stated to be substantially in the frequency range 1 to 300GHz, although sometimes it is stated to be in the frequency range 0.2 to 300GHz . It includes that part of the spectrum referred to as millimetre wave (having a frequency in the range 30 to 300GHz).

Communications systems have been proposed in which one or more communications channels are transmitted in a particular direction in the form of a modulated electromagnetic beam propagating through free space, for example the atmosphere. An advantage of such a directional communications system over a communications system which broadcasts omnidirectionally is that there is a greater degree of security in that the communications channel or channels can be directed towards a particular location. For example, if omnidirectional transmission is used, not only can others receive the transmission readily but the presence, and possibly the location, of the transmitting station can be determined.

In one embodiment, units which are spatially separated need to communicate with each other. If any of the units are mobile, then the directional communications channels

could come from any direction in an azimuthal plane. It then becomes important to establish the direction from which a communications channel is coming in order that a reply can be sent in the correct direction. Although this can be done by having a number of antennas pointing in different directions, a single omnidirectional antenna is preferred.

A known device for electronically steering a microwave beam comprises a body of ferrite material having an aperture through which the beam passes. Located on opposing sides of the aperture are magnetic coils which apply a magnetic field across the body which induces a gradient in magnetisation across the body. The resultant direction of the beam leaving the device is generally perpendicular to the gradient in the magnetic field across the body. Therefore the amount by which the beam is steered is controlled by the gradient in magnetisation. Across its width, the beam passes through the same thickness of ferrite material. Such a device is described in GB 9722720.1. If the device is provided with magnetic coils on two opposing sides of the aperture, the device can steer the beam in a single plane. If the device is provided with a plurality of magnetic coils, typically four, each being located adjacent a side of the aperture, the device can steer the beam in two or more planes, that is, conical steering. Variation of current supplied to each pair of coils provides steering of the beam to some extent, for example ±25°.

In certain applications it is desirable to scan a microwave beam through 360° in an azimuthal plane. In this context an azimuthal plane is perpendicular to the original direction of the beam before it was steered. To achieve 360° azimuthal steering a

mechanical beam steering or scanning device is used. Such a device typically has a reflective surface inclined to an axis, typically by 45°, which is rotated about that axis. A disadvantage of such mechanical scanning is that moving mechanical components have momentum and take a finite, and potentially overlong, time to stop.

According to a first aspect the invention provides a device for controlling the direction of a beam of radiation comprising an aperture for the beam of radiation the aperture having an axis and steering means characterised in that the steering means is varied so that on leaving the body the beam is offset relative to the axis and steered about it so as to define an angle θ between the axis and the steered direction and reflected so that the emergent direction of the beam from the device relative to the axis is greater than θ.

Preferably the device has a body of magnetic material which comprises the aperture. In this embodiment the beam of radiation may pass through the body. In this case the axis is parallel to and coincident with the direction of the beam before it was steered by the device. Preferably the steering means is magnetic means.

Preferably the magnetic means applies a gradient in magnetisation across the aperture. Preferably this gradient in magnetisation occupies a plane which is not perpendicular to the axis. Although the term plane is used, this describes the gradient of magnetisation in an ideal case. The gradient might be non-planar due to non-ideal conditions in its generation. Preferably the gradient of magnetisation rotates about the axis.

In an alternative embodiment the device comprises a phased array which is able to

conically steer a beam of radiation produced by it. In this embodiment the steering means is control means of the array itself which controls phases of various individual elements of the array.

An advantage of electronic beam scanning is that no moving parts are involved and halting a scan or switching the beam between particular directions can be almost instantaneous.

Preferably the axis passes through the centre of the aperture. However, it may not necessarily do so but may be a nominal axis chosen according to the direction of the beam.

The offset between the beam and the axis may be angular. Preferably it is spatial. If there is a spatial offset the angle θ may be small. It may be zero.

Conveniently the beam is reflected by a reflective surface placed adjacent to the face of the body or array from which the beam emerges. This face is the emergent face. Preferably the reflective surface is in the shape of a cone having its apex facing the emergent face and its central axis coincident with the axis of the device.

Preferably the device sweeps the beam through 360° of a plane which is perpendicular to the axis.

Preferably the beam of radiation is microwave radiation. Most preferably it is

millimetric radiation. In one embodiment it is at Ka band (26.5 to 40GHz) and in another it is at W-band (75 to 110GHz). Alternatively the radiation is in other parts of the electromagnetic spectrum, for example at higher frequencies towards, and including, optical and visible frequencies.

An embodiment of the invention will now be described by way of example only with reference to the accompanying drawings in which:

Figure 1 shows a unit to deflect a beam of radiation;

Figure 2 shows a perspective view of the unit of Figure 1;

Figure 3 shows the unit of Figures 1 and 2 in plan view; and

Figure 4 shows the unit of Figures 1 and 2 incorporated into a beam scanning device.

Figure 1 shows a unit 10 which is used to deflect a beam of radiation 12 transmitted from a microwave horn (see Figure 4). The unit 10 comprises a body 14 of ferrite material having a quarter wave plate 16 located adjacent an entry face 18 of the body 14 and a phase correcting dielectric 20 located adjacent an exit face 22 of the body 14.

Although reference is made to a beam, implying that there is a spot of energy, it is to be understood, of course, that the radiation is in the form of an energy distribution.

The body 14 provides a magnetisable medium through which the beam 12 passes. In effect therefore, it comprises an aperture. Opposite faces of the body 14, that is opposite sides of the aperture, are provided with anti-reflective coatings. The body 14 has a central axis 24 which passes through the centre of the aperture, parallel to the beam of

radiation. Pairs of biassing coils 26 and 28 and 30 and 32 are located about sides 34, 36, 38 and 40 of the body 14. The coils are wound about parallel axes which are themselves parallel to the central axis 24. As a consequence of their orientation, when an electric current is sent through the coils they are energised and apply a magnetic field to the body 14 in a direction generally perpendicular to a mid-plane of the body located parallel to, and equidistant from, the entry and exit faces 18 and 22. The magnetic field aligns internal magnetisation in the body 14 to enhance net magnetisation in a direction parallel to the magnetic field.

The effect of the magnetic field on the ferrite material of the body 14 and the interaction between magnetised ferrite material and a microwave beam is described in GB 9722720.1. A microwave beam passing through the magnetised material will interact with it and this interaction changes velocity of parts of the beam across its width. A uniform magnetisation, that is having a zero gradient, present across the body will uniformly change the velocity of the beam across its width. However, if a non-zero gradient in magnetisation is present across the body this causes a differential phase shift in the beam across its width. If the beam is circularly polarised it emerges at an angle deviated from its original direction on entering the body. If the beam is linearly polarised, which is effectively a combination of two circularly polarised beams of opposite senses, two circularly polarised beams emerge at equal and opposite angular deviations.

The unit 10 is also shown in Figure 2 in perspective view. The configuration of the coils can be more clearly seen wound about arms 42, 44, 46 and 48 which extend from

respective sides of the body 14. Since the coils produce the desired gradient in magnetisation when current in the same direction is applied, the coils of each pair can conveniently be wound from a continuous piece of wire. If the coils are wound in the same direction, the direction of the current in each needs to be in opposite directions. In this embodiment it can be seen that coils in a particular pair are wound in opposite directions. As a result, if the coils in a particular pair are driven with current in the same direction, magnetic fields having opposite directions are generated by each coil. In this way a non-zero gradient in magnetisation results. The arms can either be integral with the body 14 comprising the same material or can be separate pieces of the same or of a different material. If separate pieces are provided it is necessary to ensure that a magnetic circuit between the arms and the body 14 is provided so as to provide a medium through which the magnetic field can pass into the body.

The magnetic field produced by one of the coils, for example 26 or 30, is in an opposite direction to that produced by the other of its pair, for example 28 or 32. In this way each pair of coils induces a gradient in magnetisation across the body 14, from one side to the opposite side. If both of the pairs of coils are inducing a gradient in magnetisation, a composite gradient in magnetisation results.

If the coils in a particular pair are each energised with periodically oscillating electrical signals and the oscillating signals applied to each pair are in quadrature, that is 90° out of phase, this will cause the composite gradient in magnetisation to rotate about the central axis 24. If the coils are identical and applied currents are similar (having opposite directions where appropriate) this will cause the beam to emerge from the exit

face 22 at locations about a circular path centred on the central axis 24. A schematic representation of such a circular path 46 described by the beam 12 on the exit face 22 is shown in Figure 3. Of course, the path 46 does not have to be circular but may be any shape suitable for operation of the unit 10. Generally, the shape of the path is governed by the phase relationship of the oscillating signals applied to the pairs of the coils. Therefore, in certain circumstances, the phase relationship will be other than in quadrature.

Figure 4 shows the unit 10 incorporated into a beam scanning device 50. The unit 10 is located between a microwave horn 52 and a cone shaped reflector 54. Since the reflector is arranged so that its apex faces the exit face 22 and its central axis is coincidental with the central axis 24, it will be appreciated that as the beam 12 emerges from locations about the circular path 46, it will be reflected from a part of the reflective surface of the reflector 54 located as a circular path about the central axis. A potential problem with a cone reflector is that it naturally causes the beam to diverge significantly. One way to reduce this is to increase the size of elements in the device 50, such as the reflector 54, relative to the size of the beam footprint. Finite limits exist as to reasonable sizes for such elements, given particular applications. Alternatively the reflector 54 can be modified to have particular focussing properties. For example if the reflector 54 does not have a constant taper angle but has a taper angle which increases as the apex is approached, so that in elevational view it appears to have concave sides, then the beam can be focussed in a particular plane, ideally an azimuthal plane which is perpendicular to the central axis 24. Naturally this does not provide focussing in a plane occupied by the central axis. Therefore the reflector 54 may be replaced by a

composite set of reflectors each having suitable focussing properties in both planes. Although such an arrangement would have optimised reflection only in certain fixed directions, this may be suitable for particular applications. In one embodiment a reflector in the shape of a cone having a reflective surface bas machined or built in optimised reflective regions so that 360° scanning is possible with optimised reflection occurring in certain fixed directions.

A further refinement of the reflector 54 is to provide it with a non-reflecting end. If the relative sizes of the footprint of the beam and the offset from the central axis 24 are such that the footprint overlaps the central axis 24 then the device will transmit radiation in all azimuthal directions. If the axis of the beam and the central axis coincide, the radiation will be transmitted isotropically in azimuth. If there is a slight offset, although radiation will be transmitted in all directions, the radiation will have maximum and minimum values located 180° apart in the azimuthal plane. A non-reflecting end can ensure that the beam is reflected from a single side of the central axis 24 only and thus results in transmission of a single beam. A non-reflecting end can be provided by coating the apex and surrounding region with a microwave radiation absorbing material or truncating the end and providing either radiation absorbing means or providing means to reflect radiation in non-critical directions of the reflector 54. Assuming that the reflector has a correctly chosen cone angle, the beam will be scanned 360° through a plane which is perpendicular to the central axis 24.

Additional components are provided to optimise operation of the device 50. The quarter wave plate 16 located adjacent the entry face 18 is provided to convert linearly polarised

radiation transmitted by the horn 52 into circularly polarised radiation. However, if a horn is used which transmits circularly polarised radiation, the quarter wave plate 16 will not be necessary. It is preferred to use a beam of circularly polarised radiation because it is deviated as a single beam as is discussed above. However, if a beam of linearly polarised radiation is used, which is consequently split into two circularly polarised beams, they would be reflected by the reflector 54 at an angular separations of 180°, thus doubling the scanning rate of the device.

The phase correcting dielectric 20 is provided to optimise the direction taken by the beam 12 as it emerges from the exit face 22 of the body 14 and is reflected off the reflector 54. As can be seen in Figures 1 and 4 the passage of the beam 12 through the body 14 is schematically illustrated as a curved path 56. As a result the beam will tend to emerge from the body in a direction not parallel to the central axis 24. The phase correcting dielectric 20 changes the direction of the beam 12 so that it travels towards the reflector 54 in a direction parallel to the central axis 24. Such a direction is preferred so as to minimise the size of the device and reduce divergence in the reflected beam. The phase correcting dielectric is in the form of a shallow cone having a large taper angle. The taper angle is chosen to provide azimuthal scanning.

Although the unit 10 and the beam scanning device have been described transmitting radiation, in certain embodiments they are to be used to receive as well as to transmit. For example, in a communications system, if a station receives a signal to which it is convenient or it is necessary to respond, such as an interrogation signal, it is desirable to determine the direction from which the signal originates. In this way a response

signal can be transmitted in that direction only rather than omnidirectionally.

In a particular embodiment of a communications system a typical interrogation sequence might proceed as follows. The station to be interrogated is identified and an interrogating station transmits an interrogation signal. The interrogation signal typically has a first portion simply comprising a pulse of electromagnetic radiation which can be detected by the station being interrogated to know that an interrogation sequence has begun. It is not necessary for the pulse to contain any data. It may be about 100μs long. Following the first portion, a second portion containing data is transmitted, for example in a burst 300 to 400μs long. Therefore, the station being interrogated has 400 to 500μs to find out the direction from which the interrogation signal is originating in order that it can send its response signal in the correct direction.

If the device 50 is also being used as a transceiver, that is both to transmit and to receive radiation, it can scan to receive. In such a receive mode, at any single point in time the unit 10 is electrically biassed by a small amount such that radiation is being preferentially received from one sector and less preferentially received (but still received to some extent) from other sectors. The coils of the unit 10 are electrically biassed such that the composite gradient in magnetisation rotates about the central axis 24, thus scanning through 360° the preferential receiving and less preferential receiving sectors. When the electromagnetic pulse is received by the unit 10, irrespective of its angular orientation with respect to the preferential receiving sector, some of its power will be detected and processing means associated with the device 50 will determine that the station being interrogated is, indeed, being interrogated. Following this, as the receiving

sectors are being scanned through 360°, the processing means can identify the electrical biassing at which maximum electromagnetic power is received and thus determine thc direction from which the interrogation signal originates. Once the direction has been identified, in making its response the unit 10 of the responding station can be electrically biassed so that there is a clear offset between the beam 12 and the central axis 24 to transmit the beam in a single azimuthal direction only, towards the interrogating station, rather than isotropically.

In another embodiment of the device 50, the unit 10 is omitted and replaced with a phase array. Controlling the relative phases of elements of the array enables it to output a beam in chosen directions and therefore, by dynamically altering the relative phases of the elements, to steer the beam conically. Since the beam can therefore be used to describe in a nominal plane a circular path similar to path 46, then, if used together with a suitably located and suitably shaped, for example conical, reflector, it can also be used to scan the beam through an azimuthal plane. In such a modified system, it would be necessary to physically separate the array and the reflector to a sufficient extent so that the steered beam falls largely or wholly on one side of the central axis of the reflector at any one time. By careful control of the relative phases, the beam could not only steered but also focussed so that a relative narrow beam is produced on reflection by the reflector. It will be understood that if such a scanning transmitter is produced, the array could be configured so that it can receive radiation as well. In this case, the phased array could scan for received signals in a manner similar to that described above and, when such a signal and its direction has been determined, transmit a response in the desired direction.

Generally, there are systems other than communications systems in which determining the direction of origin of radiation is desirable. Such systems may be tracking systems.

1/2

Off axis beam deflection

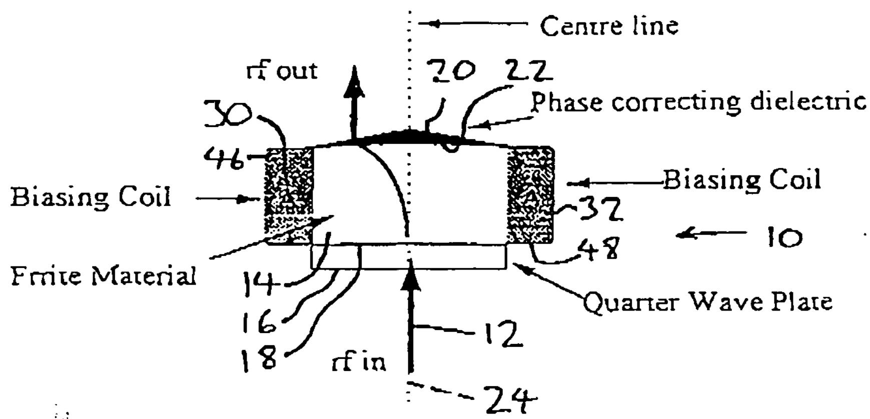

FIGURE 1.

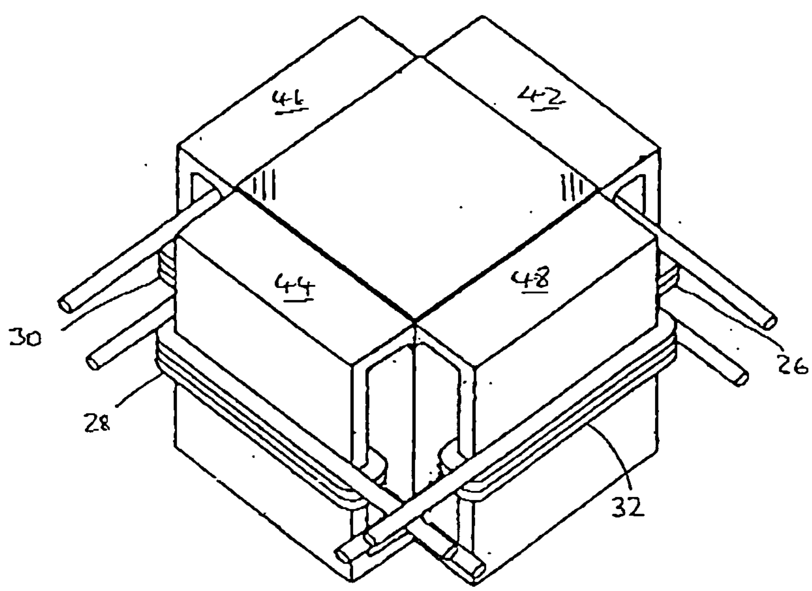

FIGURE 2.

2/2

Off axis beam deflection

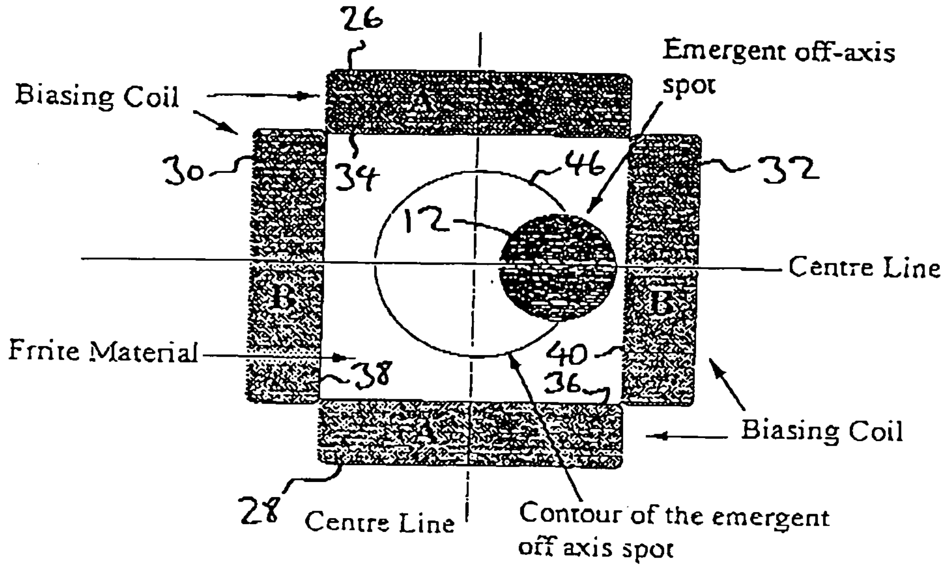

FIGURE 3.

Electronic Beam Scanning

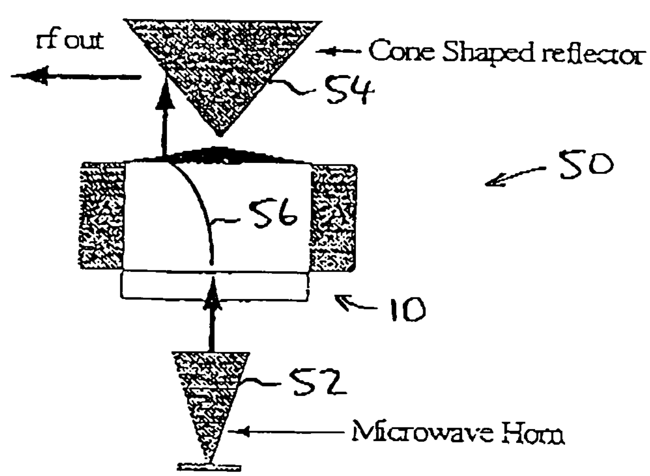

FIGURE 4.

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